Evaluating the Effect of Embedded Sensors on CMC Mechanical Properties

Craig Smith, Ohio Aerospace Institute

Doug Kiser, Robert Okojie, Laura Evans, NASA Glenn Research Center

Anthony Calomino, Patty Howell, NASA Langley Research Center

Presented at The 36th International Conference and Exposition on Advanced Ceramics and Composites

January 23, 2012

Evaluating the Effect of Embedded Sensors on CMC Mechanical Properties

Craig Smith, Ohio Aerospace Institute

Doug Kiser, Robert Okojie, Laura Evans, NASA Glenn Research Center

Anthony Calomino, Patty Howell, NASA Langley Research Center

Presented at The 36th International Conference and Exposition on Advanced Ceramics and Composites

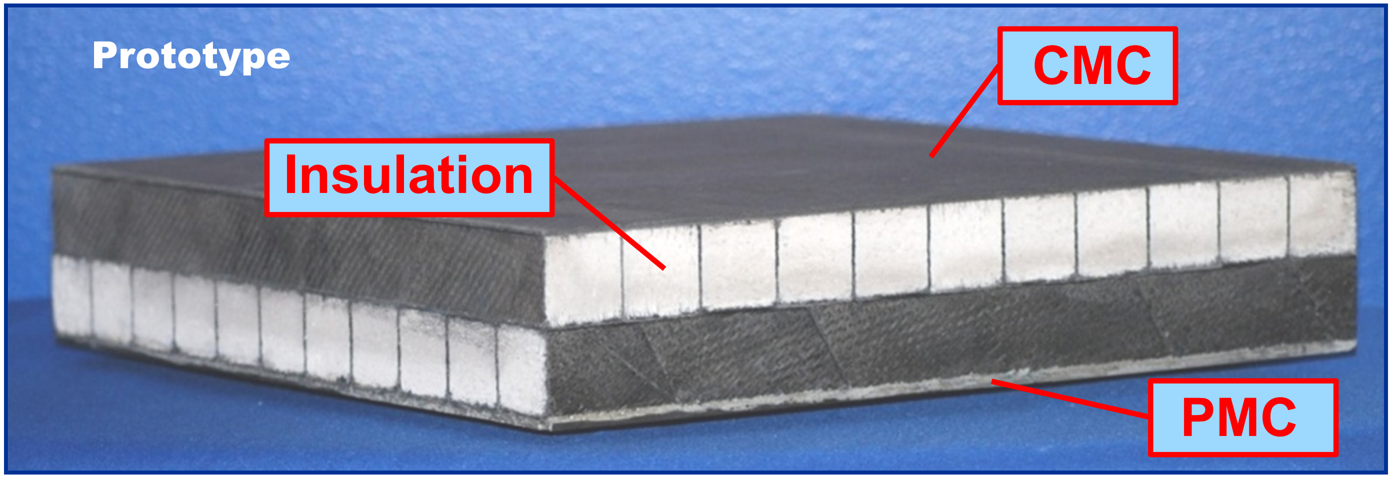
January 23, 2012

Structurally Integrated Thermal Protection Systems (SITPS)

A NASA-led interdisciplinary team with members from several NASA centers and Industry has been developing SITPS (structurally integrated thermal protection system) for use on hypersonic vehicles.

Structurally Integrated Thermal Protection Systems (SITPS)

"A TPS that has both an integrated mechanical and thermal load carrying capability <u>and</u> has the ability to share mechanical loads with adjacent TPS structures"



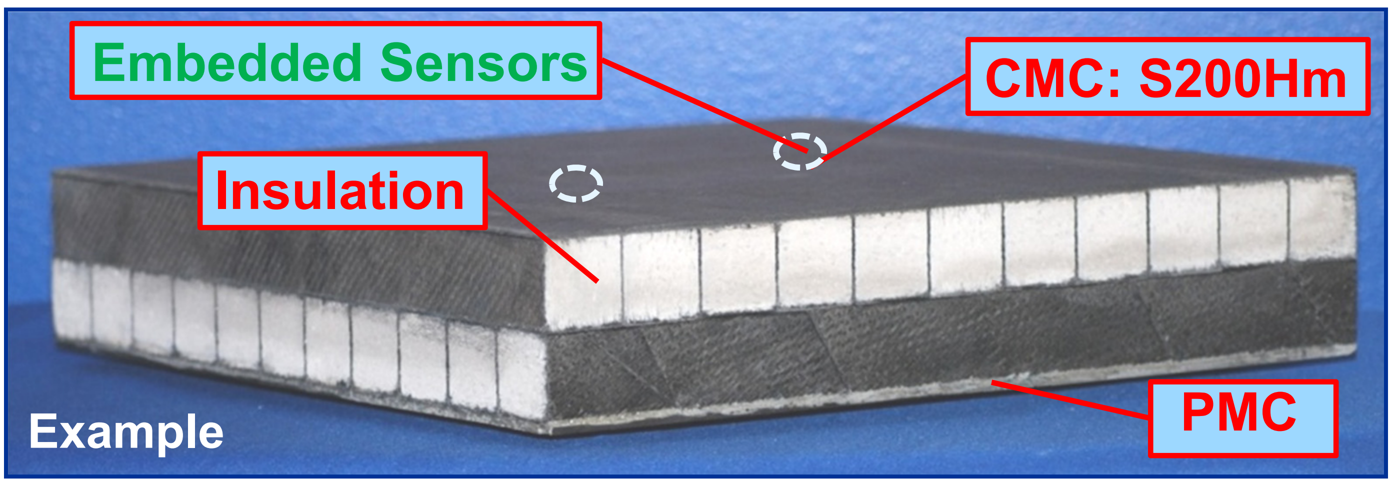
Driver for NASA's SITPS development:
The development of an advanced TPS that is <u>both structurally and volumetrically efficient</u> using high-temperature ceramic matrix composite and light-weight insulation materials

Contact:
Craig A. Stephens
Aerostructures Branch
NASA Dryden Flight Research Center
Phone: (661) 276-2028
Craig.A.Stephens@nasa.grc

Hypersonics SITPS Embedded Sensors Subtask

Vision

Fully-functional embedded wireless sensors for use in SITPS (structurally integrated thermal protection system)—capable of transmitting and receiving information from within a CMC (ceramic matrix composite) surface layer operating at temperatures above 2000ºF.



Objectives (Note: Two Parallel Efforts Within Task)

→ **There are Materials and Sensors Aspects, With Overlap**

1. Characterize embedded SiC “dummy” chips in representative SITPS OML (outer mold line) composite material to help us understand the thermal and mechanical interaction between the SiC chips (including the metallization) and the composite.

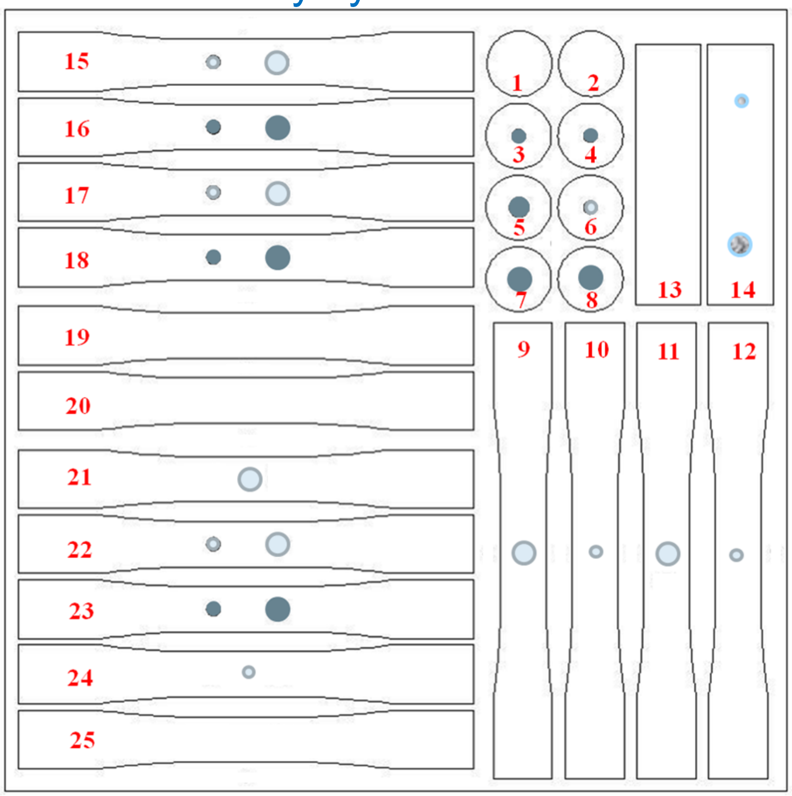
    Understanding this interaction is the first step in assessing the feasibility of embedding sensors in SITPS (specifically, in the CMC outer layer).

2. Characterize the functional parameters of GRC-developed high-temperature strain gauges in a surface-mounted configuration.

Surface Mounted Sensors → **Surface Mounted Wireless Sensors** → **Embedded Wireless Sensors**

Embedded ‘Dummy Sensor’ Panel

- Composite panel produced by ATK COIC, with embedded SiC disks
- S200Hm composite consisting of Hi-Nicalon SiC fibers and SiNC matrix
- Two types and sizes of disks were examined
  - Large (7.5 mm diameter) and Small (5 mm diameter)
  - Single crystal 6H SiC
  - Polycrystalline SiC

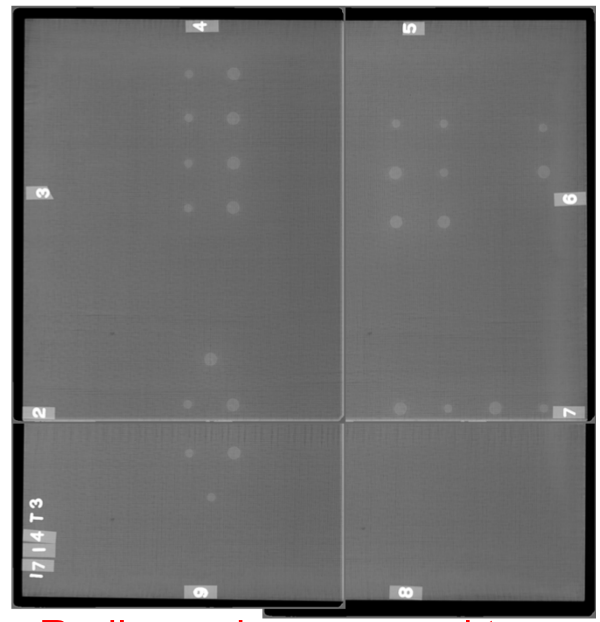


15 Tensile samples were produced, with 5 variations

8 ILT samples were produced

All disks were 0.25 mm thick

- 6H Single Crystal SiC
- Polycrystalline SiC



Radiography was used to verify disk locations prior to specimen fabrication

NDE of Specimens

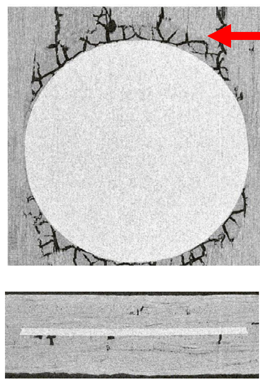
NASA LaRC Microfocus X-ray Computed Tomography System

HMXST High Performance Real-Time X-ray Inspection System

- Advanced microfocus x-ray system, capable of resolving details down to 5 microns, with magnifications up to 160X.
- Sample can be manipulated with 5 axes of freedom, while continuously viewing the image on a monitor.
- Defects/features of interest can be rapidly located, zooming in for detailed analysis.
- System is supplied as a complete, large dimension radiation enclosure, with x-ray, manipulator and imaging controls housed in a separate control console.

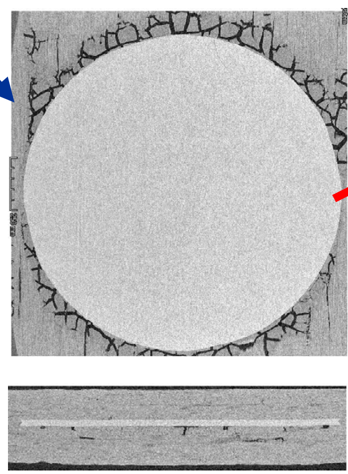
Computed Tomography of Samples Prior to Testing

23



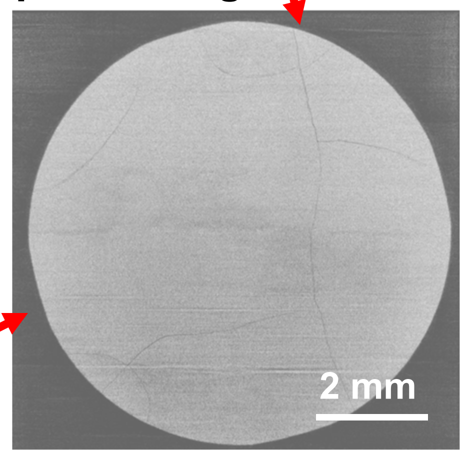
2 mm

The matrix surrounding the disks exhibited cracking



2 mm

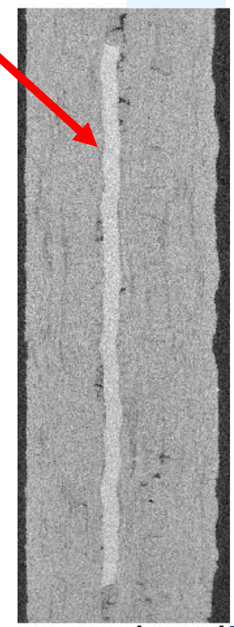
Almost all SiC disks were cracked after processing



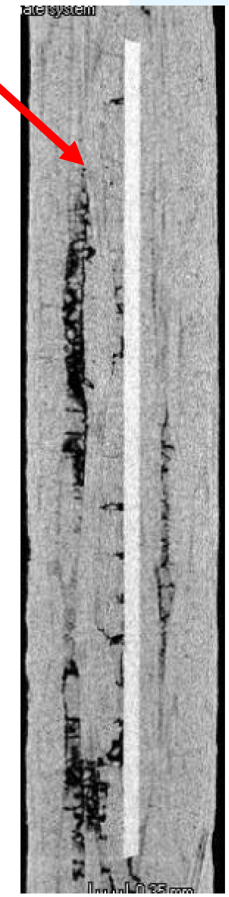
Some samples had large porosity above or below the disk

Some disks appeared deformed and wavy after processing

10



17

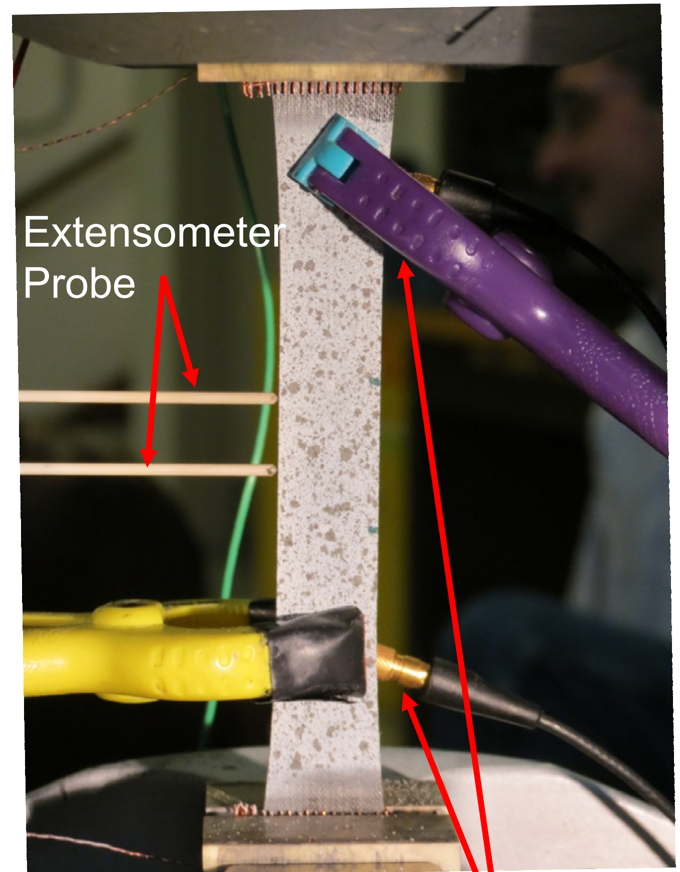


1 mm

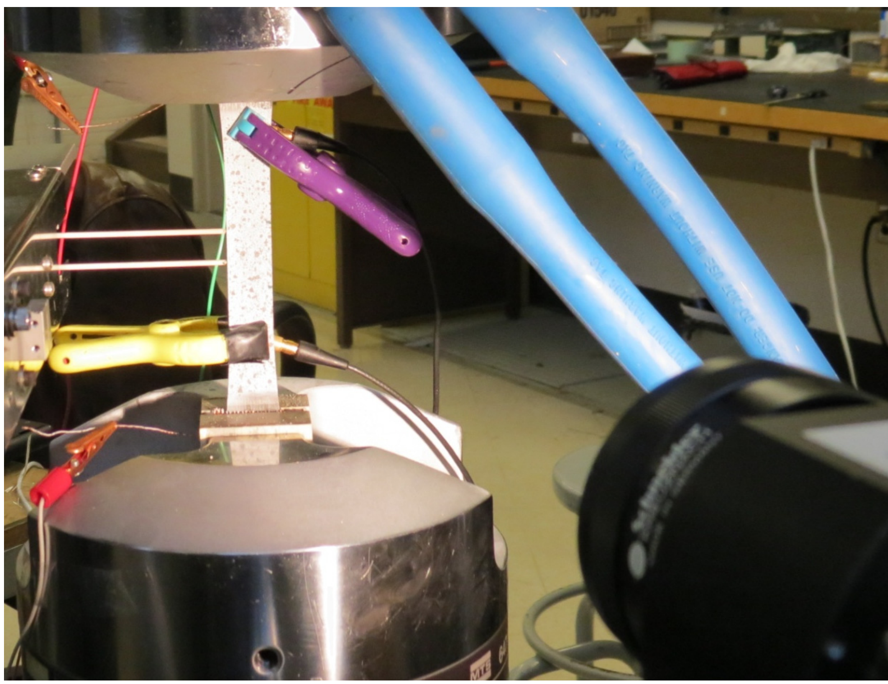
CT slices through the embedded SiC disks

Room Temperature Tensile Tests

- Acoustic Emission monitored throughout test
- Digital Image Correlation software utilized for strain visualization
- Contact probe extensometer with 12.7 mm gage and 4% range used
- Loaded at 4 kN/min

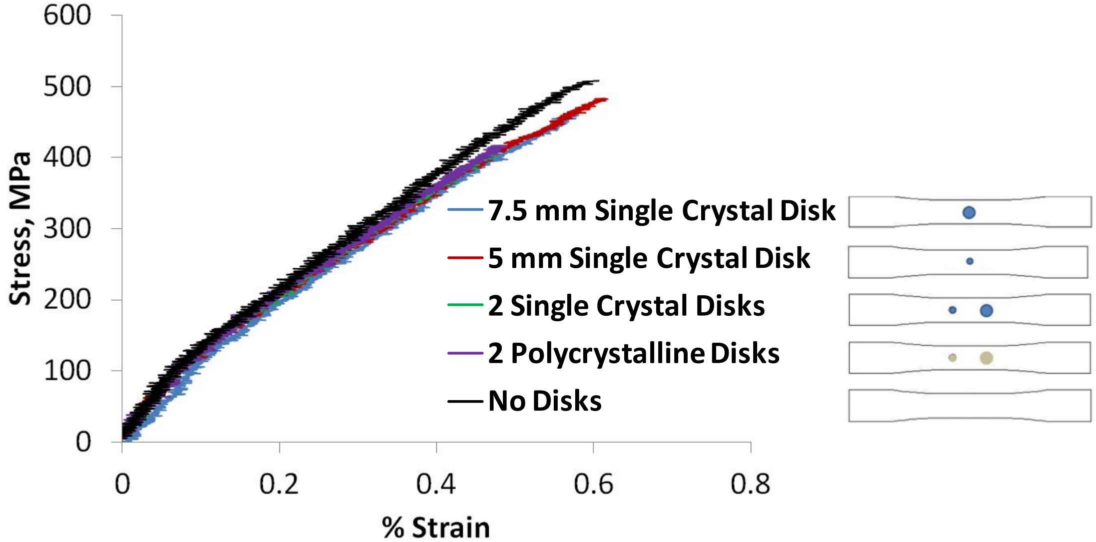


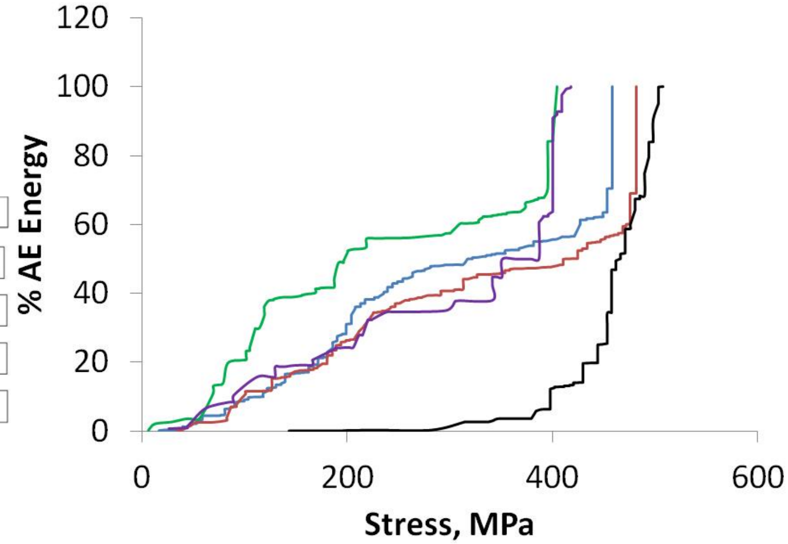
Acoustic Emission Sensors



Digital Camera for Strain Visualization

Room Temperature Results





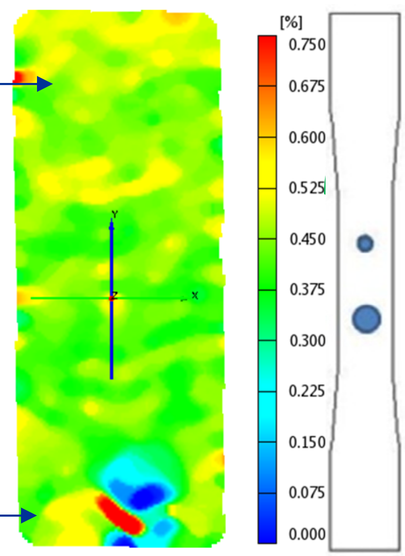
Embedded Disks	E, GPa	0.005% Offset Stress, MPa	UTS, MPa	Ultimate Strain, %	First AE Stress, MPa	First Loud AE Stress, MPa
1 Large Single Crystal	125	120	460	0.579	16	39.2
1 Small Single Crystal	130	140	483	0.615	34	47.3
2 Single Crystal Disks	130	135	406	0.476	6	10.6
2 Polycrystalline Disks	125	140	417	0.486	26	47.7
NONE	135	150	508	0.607	143	313.7

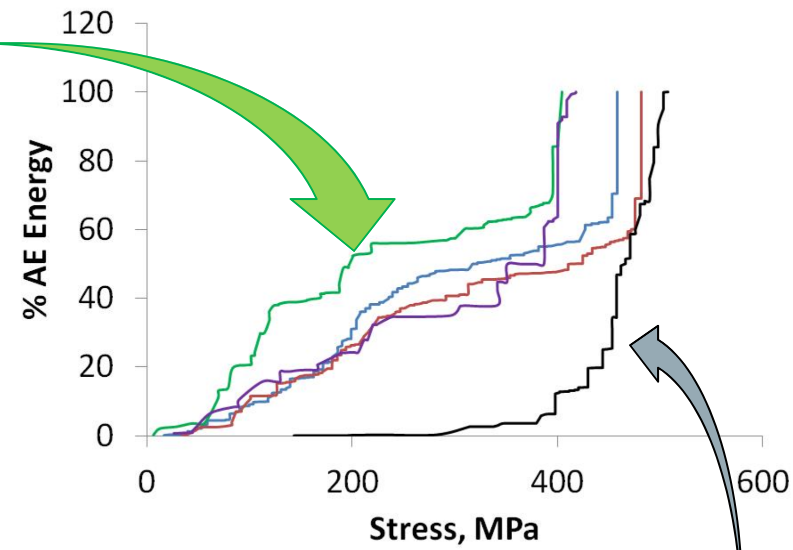
- Modulus was only slightly reduced for samples with disks
- Failure strain was similar for baseline and single disk samples
- Acoustic Emission began earlier for samples with embedded disks
- 2-Disk samples had a 20% reduction in strength and strain
- All samples broke near the center or edge of a disk

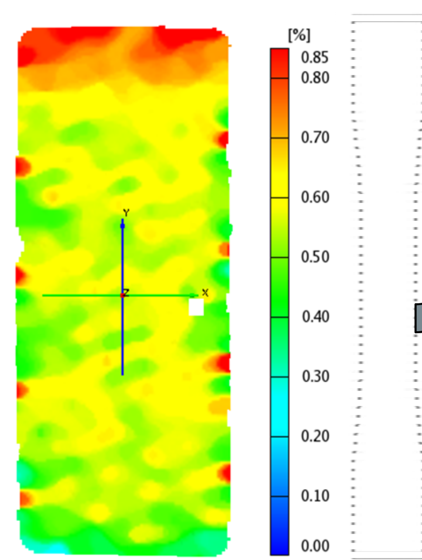
Room Temperature Results

Small Disk
(5 mm diameter)

Large Disk
(7.5 mm diameter)



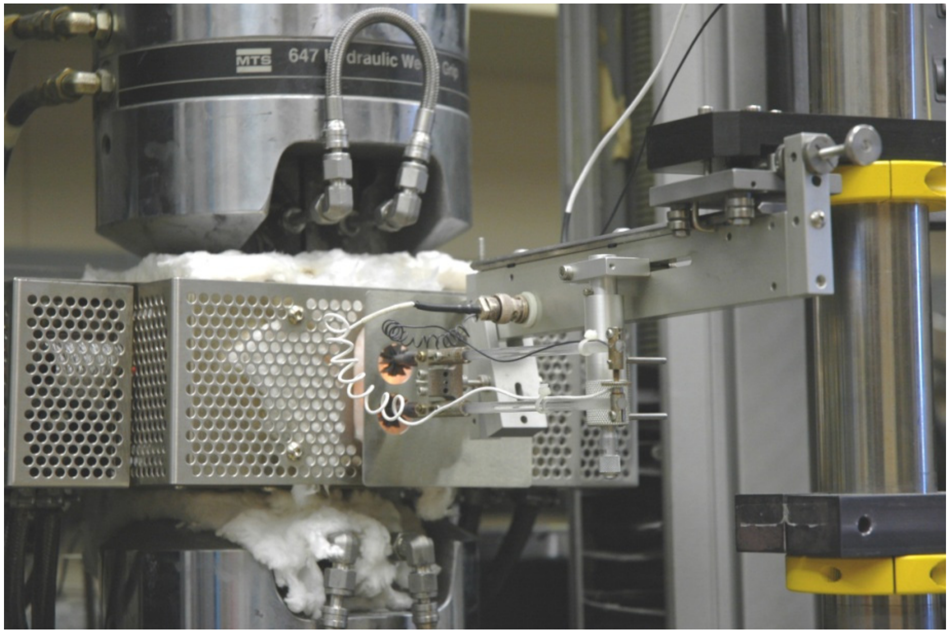




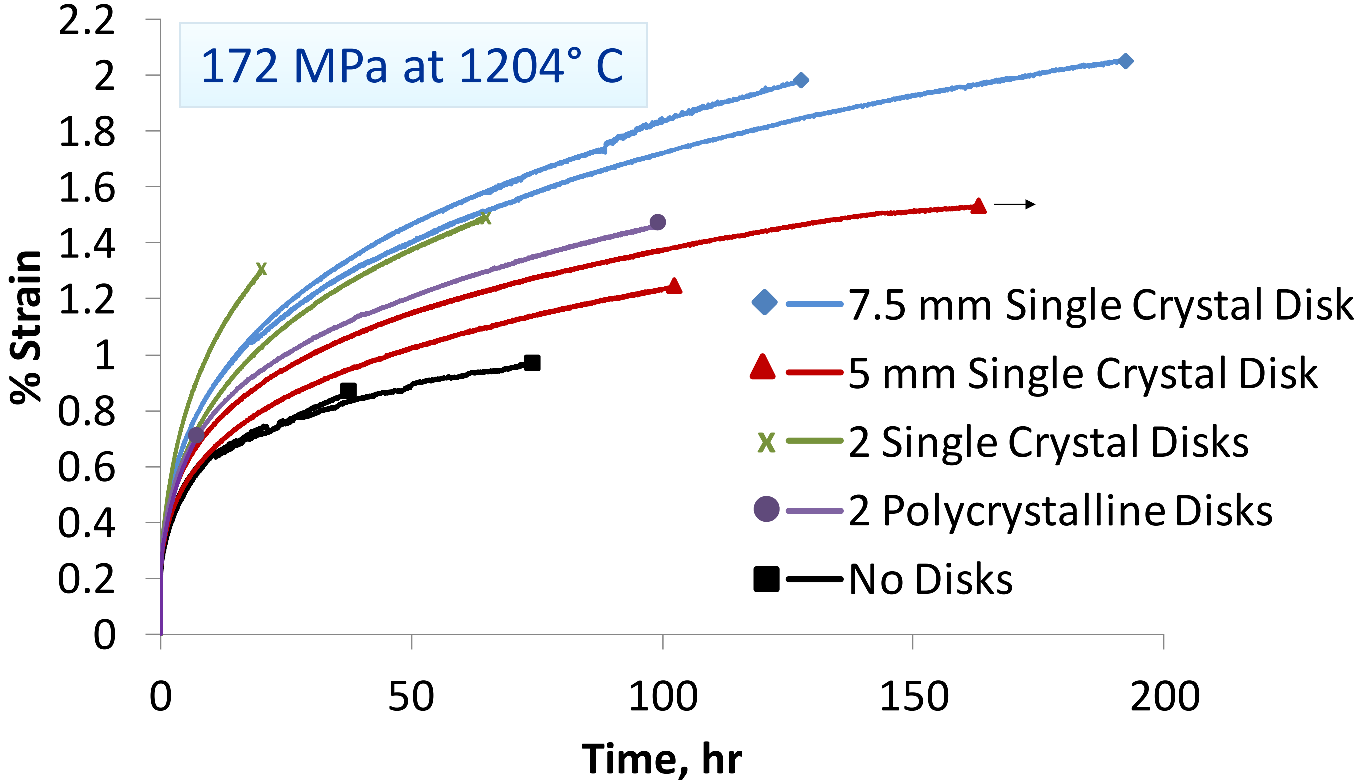
- **Baseline sample with no embedded disks showed cracks forming, distributed along the edges**
- **Embedded disk sample showed high local strain near the large disk, which is where failure occurred**
- **AE events initiated much earlier in embedded samples than for the baseline material**

Creep in Air

- All samples tested at 172 Mpa (25 ksi) and 1204° C (2200° F)
- Strain measured with a capacitance probe extensometer (25.4 mm gage)
- Heated to 1204° C and held
- Loaded to 172 Mpa at a rate of 0.127 mm/min
- Load held constant until failure



Creep Results

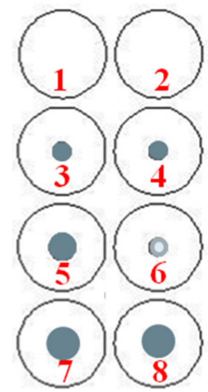


- Samples with embedded disks had greater creep rates
- Compared to the baseline, the time to failure was similar or longer for samples with disks
- For samples with fewer and smaller disks, less creep was observed

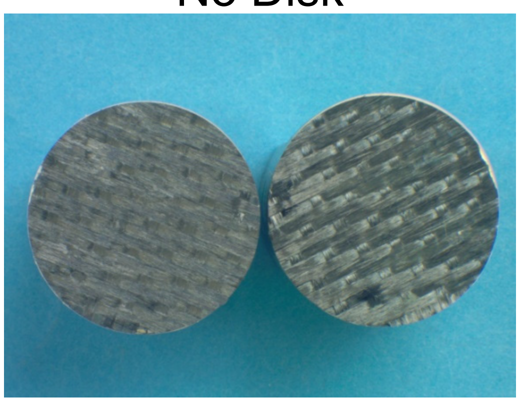
Interlaminar Tension

- Small polycrystalline disks had no effect on ILT strength (good bond)
- Small single crystal disks broke at the disk and had ~10% reduction in strength
- Large polycrystalline disks broke at the disk and had ~25% reduction in strength

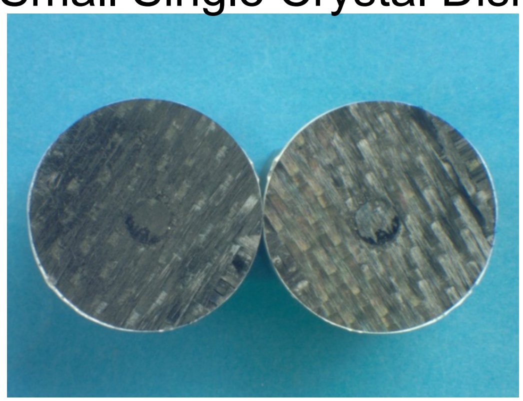
	Strength, MPa	Fracture Location
NO Disk	24.2	In Composite
NO Disk	9.6	In Glue
Small Polycrystalline	26.3	In Composite
Small Polycrystalline	25.7	In Composite
Small Single Crystal	21.7	At Sensor
Large Polycrystalline	18.0	At Sensor



No Disk



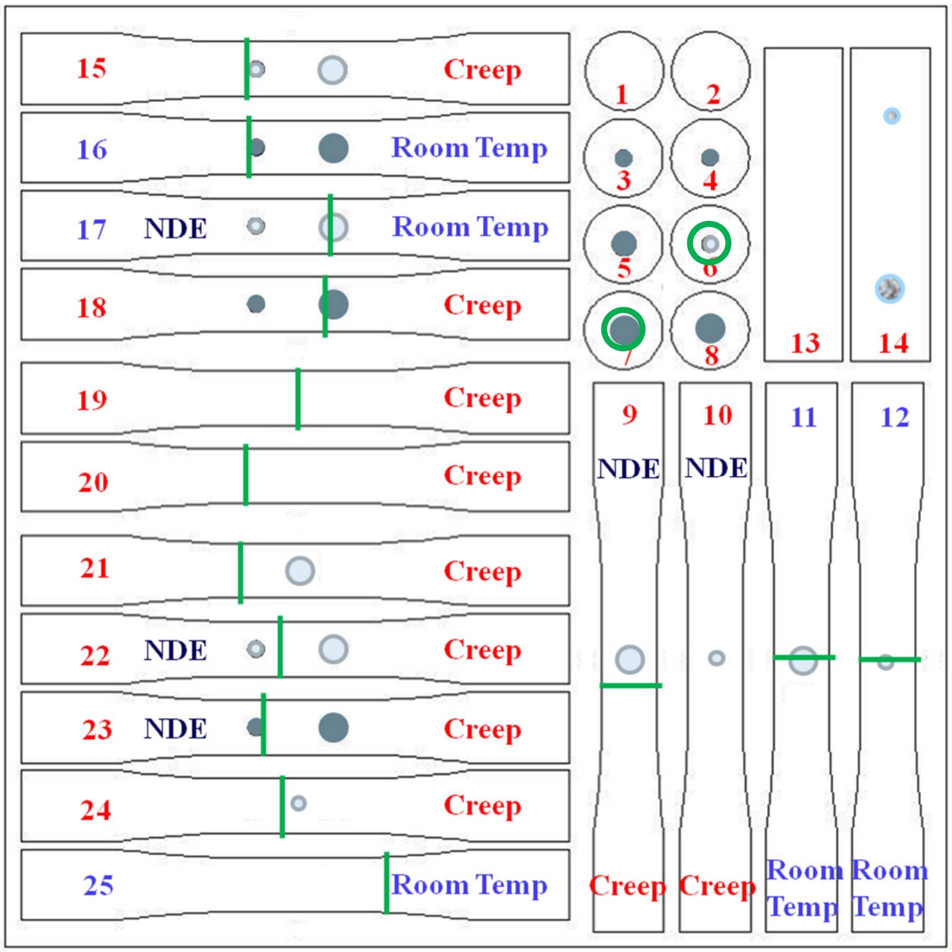
Small Single Crystal Disk



Large Polycrystalline Disk

Fracture Behavior

- Green lines indicate the location of the fracture
- All room temperature samples and most creep samples broke near the disk location



Conclusion

- For future work, changes would need to be made to prevent disk cracking
- Individual disks caused a small reduction in room temperature strength
- Samples with two disks had a 20% room temperature strength reduction
- Digital image correlation and acoustic emission indicated that cracking initiated near the disks
- The creep rate increased with larger disks, although life was not negatively impacted

Acknowledgements

- A. Piazza and C. Stephens, NASA Dryden Flight Research Center (Edwards, CA)
- T. Easler and R. Plunkett, ATK COI Ceramics, Inc. (San Diego, CA)
- R. Parker, NASA Langley Research Center
- D. Roth, NASA Glenn Research Center
- R. Rauser, University of Toledo
- N. Wilmoth, ASRC Aerospace